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Designing projects for motivating students towards scientific exploration: Application to student mentoring

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ABSTRACT

Every summer in the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory, students are brought in to gain interesting research and development experience. In this work, we will review some case studies of past research experiences with students inside and outside NIF, that led to successful journal and conference publications. Several of these works will be reviewed to demonstrate how problems were chosen and defined so that meaningful results could be obtained within a limited time frame. It is anticipated that success with such projects will go a long way in motivating students in their future graduate career. Projects from laser measurement, optical computing and application of matched filtering in laser beam alignment will be reviewed to demonstrate this approach.

Keywords: laser measurement, pattern recognition, matched filtering, position detection, high power laser, optical alignment.

1. INTRODUCTION

"If I have seen further it is by standing on the shoulders of Giants" has been attributed to Newton. However, it also expresses a profound truth about scientific progress in general. When reviewing scientific proposals, reviewers are quick to criticize "this work is not innovative enough and only offers incremental progress made on the author's previous work, or someone else's previous work". When training a fresh graduate student in research, one very effective method is to bring the student to the level of the shoulder of a giant and then show him or her the next step, in an incremental way. What do I mean by this? Consider the case study presented in the next section.

2. EXTENSION OF PREVIOUS WORK

One of my first experiences in research was through an optoelectronic graduate course with less than a dozen graduate students. The instructor (Professor Mohammad Karim, currently at University of Massachusetts Dartmouth) gave us a research assignment as part of a class assignment. The project demonstrated how to measure the diameter of a Gaussian laser beam. The method was to scan the beam across a rectangular periodic grating (known as a Ronchi ruling) and measure the minimum and maximum power transmitted through the grating. Then from a characteristics curve, which relates the ratio of the beam radius to grating period to the transmitted power ratio, $k = P_{min}/P_{max}$, one can measure the radius, an unknown quantity, of the Gaussian laser beam. A typical curve is shown in Figure 1 with a more detailed description in Ref [1]. One of the problems of the Ronchi ruling is that when the diameter of the ruling is smaller than 40% [1] of the grating period, the radius is hard to measure because the power ratio approaches zero for that radius range. The class was to devise a way so that the curve could be extended to the lower regimes of the measurement.

If we stop here for a moment, we realize that this represents an interesting challenge of extending the limit of things. There are many scientific progresses that could be defined in this form. For example in NIF, if we can extend the neutron yield curve, we may achieve fusion, which will be an amazing scientific breakthrough!

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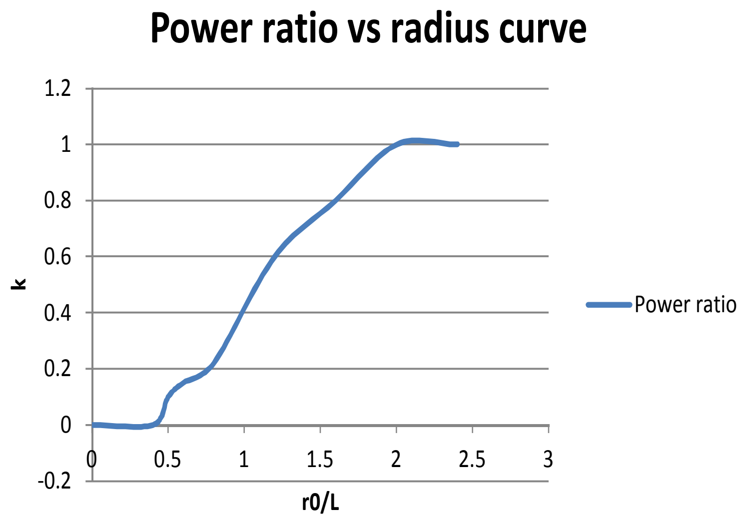
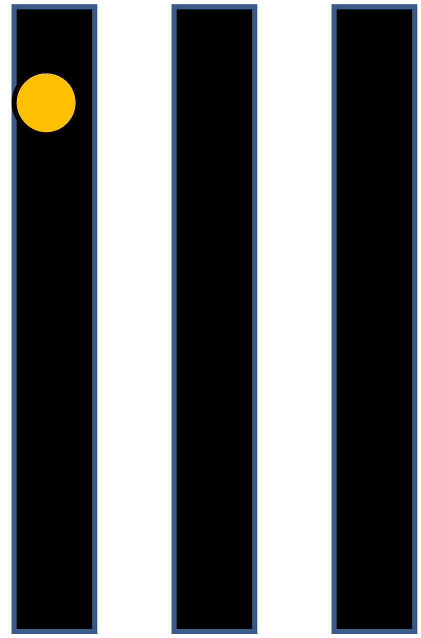


Fig. 1. K (P_{min}/P_{max}) versus r_0/L using Ronchi ruling



The limiting factor becomes clear when one discovers that the complete beam is blocked by the 50% dark region of the ruling. Any radius less than 40% will give a zero minimum power thus the ratio, thus it follows that P_{min}/P_{max} will also be zero. As a student, you can understand the problem of the current approach. To solve it you can imagine variations to the simple rectangular grating. One could vary things like the dark to bright transition or the duty cycle of the periodic grating, so that there is some nonzero minimum power. As a class project, we were asked to apply triangular and sinusoidal grating and evaluate the performance of the new system.

As students in the optoelectronics class we were also introduced to the basics of Gaussian laser beam, and method of calculating the power when the beam is passed through transmitting medium; therefore, by being a member of this graduate course, placed us somewhere on the shoulder of the giant so that we could comprehend the proposed problem. Eventually, the class did solve the problem and published the result [2]. It was amazing to see your name in a journal publication, and at the same time it was training. We got the sense that things are doable.

One may ask what type of publications are good for formulating this type of student project, which may lead to new and novel work. My experience is papers that are good for student projects are typically shorter in length. One could find examples of shorter papers published in many journals. For example, in Electronics Letters, by design all their papers are short. Other sources are Optics Letters, Optical Engineering and Applied Optics and of course, all the IEEE publications and equivalent Society publications.

When I started teaching in a university, one of the very first classes I was assigned was a numerical methods class. I did not forget that lesson I learned from my own graduate class. I gave a problem to the class as a final project. The project was: Given the measurement system using triangular grating, evaluate what will happen with an exponential grating. The class came up with the novel solution, which was an analytical as well as a numerical solution using numerical integration, which was one of the objectives of the class. We submitted the paper to the OSA annual meeting at Boston. One of the students, Jeanne Smith, drove to Boston, and presented the paper [3]. It was a great inspiration for her. Only the abstract was published in OSA, but later we published the paper in a journal [4], Yes, you guessed it. The following year I asked the class to use a logarithmic function.

3. A SMALL PROBLEM CAN LEAD TO A GREAT SOLUTION

As a second example, I want to present another short paper by Yao Li et al. [5]. This was a time when I was a new PhD student. When my PhD advisor (Prof. Mohammad Karim) gave us the problem referred to in reference 5 and asked two of us (A. K. Cherri, University of Kuwait) "how did the author came up with a design?". Li [5] showed the design of an arithmetic full adder using spatially encoded 2x2 pattern using polarized pixels. The first assignment was for us to verify that the solution given in the paper did indeed work. Then as we uncovered and solved the mystery, what we really discovered was a design methodology: a systematic way to design arithmetic and logic circuits [6]. It was like a gold mine! And a PhD thesis came out of it!

The clue for discovering the solution came from digital design, where you start with a truth table, write the logic equations, and then minimize algebraically or use K-map technique [7]. We had to come up with a way to represent logic equations optically i.e. by using optical properties. Once we wrote equations, we could solve them and show that the solution provided by [5] was indeed one of many possible solutions. Sometimes the investigation of a smaller problem may lead to fantastic and far reaching results. The challenge is to present problems that excite the young mind and unlock their creativity.

4. SUMMER STUDENT PROJECT: FLEXIBLE MATCHED FILTER

Matched filtering is a technique to detect an object in the presence of noise. Given access to powerful signal and image analysis tools such as Matlab or IDL, it is not difficult to give the student a background in matched filtering and have him implement a small matched filtering problem. Few years back, I had a summer student from Clemson University. I asked him to work on two different projects, one using Machine learning for optical defect classification. The second one was a matched filter template design. Matched filtering is also a powerful position detection technique, which enables one to detect the beam position of NIF beams and perform beam alignment with remarkable speed and accuracy. One of the beams we were having some practical challenges is shown in the Fig. 2.

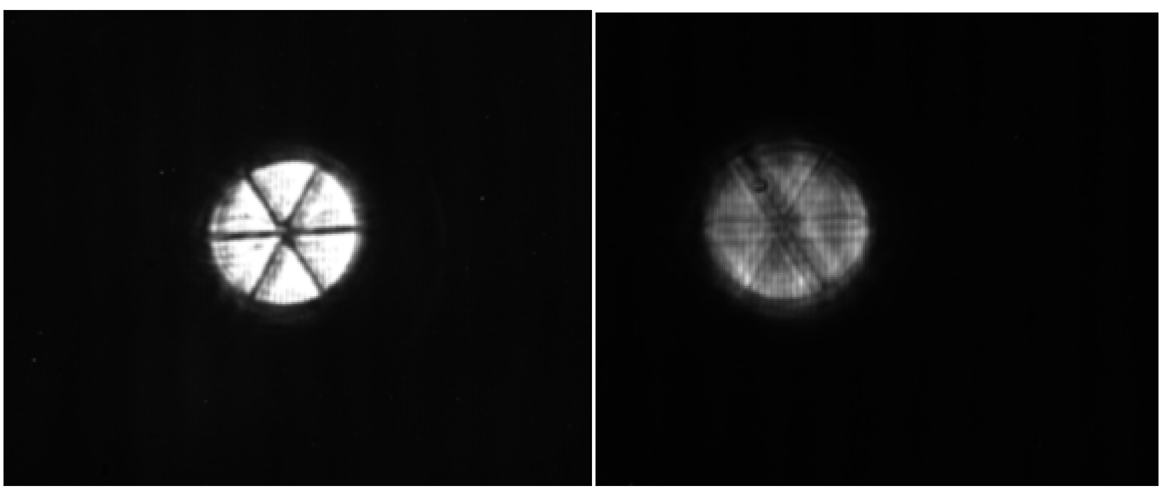


Fig. 2 transport spatial filter pass 1 image

We had been using a circular edge as a template for many alignment loops with circular disk type image. One of the problems of this particular beam image was that edges of the beams could be fuzzy, therefore a pure circular template would lead to right or left bias as there are fuzzy edges of the circle. Therefore, the center location will be biased and oscillating leading to an unstable alignment loop. The problem was to design a template using concentric geometrical lines, where the angles will be defined externally, and the hypothesis was that using these internal line structure the detection spot will be well centered. After the student finished the design, he implemented the solution in FPGA. Two journal papers resulted from this work [8,9]. This mathematical filter was flexible enough which allowed us to adjust each beam template with a unique angle to the best matched filter to achieve a stable beam positon.

Other extension of the above work was done by the student after having applied the matched filtering technique to NIF beams, where he applied phase-only matched filtering to finger print recognition [10], after he returned back to his college. Another very similar problem that was recently encountered in NIF is related to pinhole alignment and is another example of a possible student project. In pinhole alignment, the edge of the pinhole is matched to a circular ring whose radius is adaptively determined from the image. The technique works very well until we encounter a beam which looks like the following:

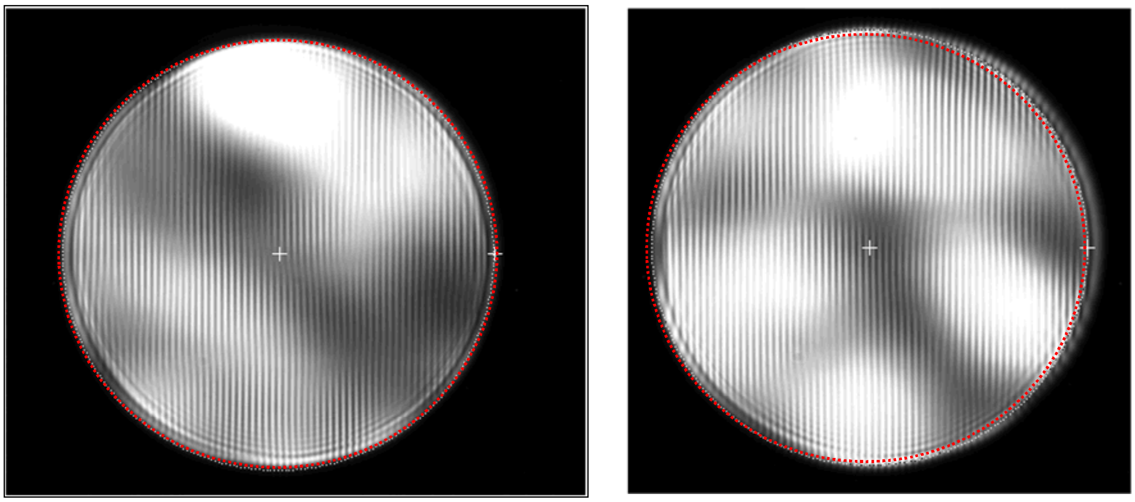


Fig. 3 Pinhole image with fuzzy edges

The vertical fringe pattern observed in the clear aperture of the pinhole in Fig. 3 is due to interference between two coherent backlighting beams separated laterally by 17 mill radians and overlapping in the image plane. Edge detection is used to find the edge and a radius search is used to find the best fit circle for the pinhole. However, the center measurement using the single radius adaptive solution is unstable when the circle has a fuzzy edge due to defocus of the two co-imaged, coherent sources. The center oscillates as shown below in Fig. 4 between two clusters, as the matched filter latches on to the left, right or both left and right pinhole edge. Fig. 5 shows some diagnostics of this position instability.

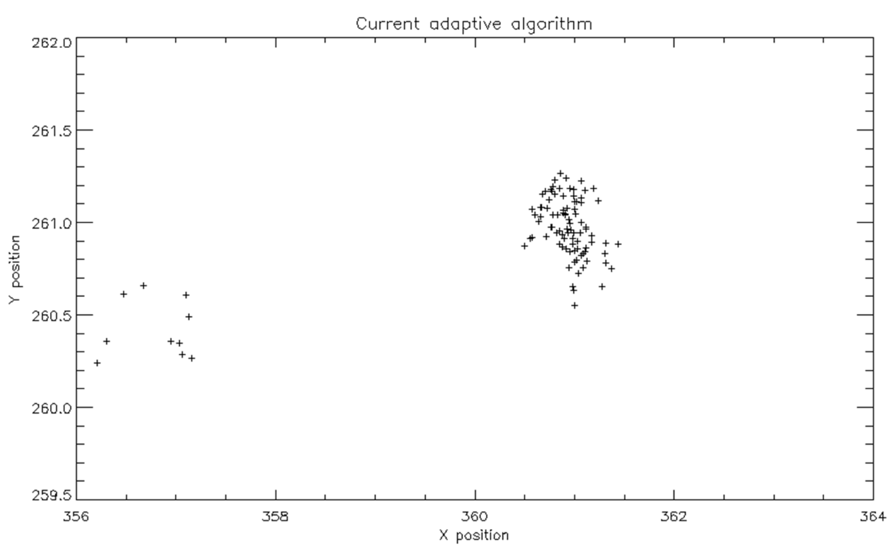


Fig. 4 Center location for a set of images taken at the same position

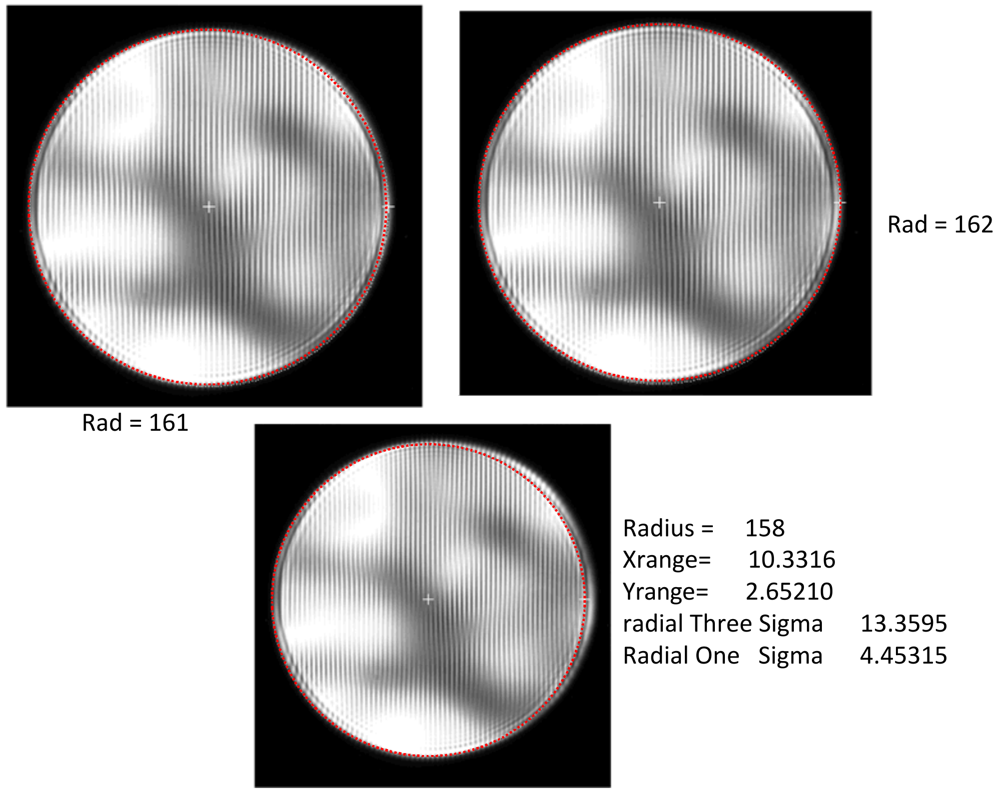


Fig. 5 Matched Center locations for three different radii for three images from the set

However, using a fixed radius (162) shown in top right corner of Fig. 5 as big as the combined circle instead of adaptive one, we get a very tight distribution as shown in Fig. 6, indicating stable position detection.

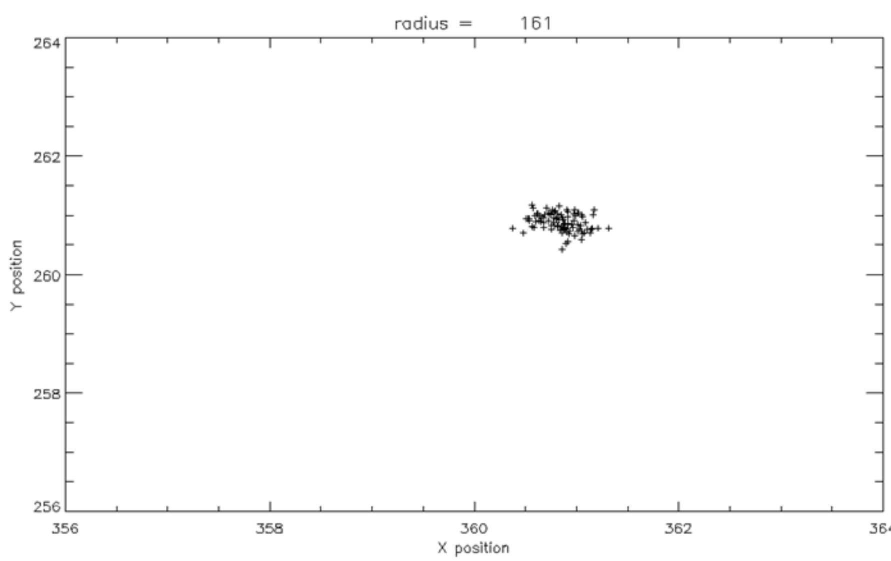


Fig. 6 Center location for a set of images taken at the same position with fixed radius template

In a laboratory research environment, such as ours, there is little or no course work offered. How does one design a successful and rewarding project and at the same time make the experience challenging or non-trivial for the student. One approach might be to give or assign the student the task of learning the history and background of the research area. In that way it empowers the student and makes them be part of on-going process, not just pressing the enter button or running some tests. I think that this should be part of the goal of all Summer projects as they learn a sound method of systematic scientific enquiry. In addition, the project should have the high chance of success.

5. STANDING ON THE SHOULDER OF A GIANT

How does one get to the shoulder of a giant? In US universities, graduate courses play a major role to achieve this. A PhD from many countries outside US may not allow for such an extensive selection of graduate courses in their graduate programs. More often, in these (non US) institutions PhD candidates are purely research oriented. Graduate courses help build the mathematical and theoretical foundation to read and understand other published research work in their area of graduate course work. Invariably, many graduate courses involve reading and presenting others' research results. Thus this is a continuous and systematic process of knowledge transfer, through graduate course work. As new courses are being developed or updated, research from PhD theses often enters into the text books, and becomes part of the regular graduate curriculum. Thus, we are continuously standing on the shoulder of the giants which in turn allow students and researchers standing taller and seeing further more than their predecessors. In addition, it leads to the development of a broader capability to explore newer topical areas well beyond PhD research area.

5. CONCLUSION

In this paper, we discuss one way to promote and improve the success rate for new students entering the graduate school in their research. The idea is to increase the student's competence and interest through course work, while at the same time use the current knowledge developed in the course work, to extend the current advances incrementally to new levels.

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